Appendix G
Conceptual Study of Water Treatment Alternatives

G.1 General

This report examines alternative water treatment processes for two potential water treatment plants proposed for the service area of the Northern Governorates Water Authority (NGWA), designated as:

- The KAC WTP (King Abdullah Canal Water Treatment Plant).
- The Wehdeh WTP (treating water from the Wehdeh Dam, currently under construction).

The WTPs will be designed to meet the levels permitted in the Jordanian drinking water standards JS 286:2001 that are listed below in **Tables G-1** to **G-7**. The conceptual design also complies with the Recommendation of the Higher Committee for Water Quality dated July 2001; a translation is attached as **Annex G.1**. During the design phase, the GoJ must provide the designers with a current set of the complete water quality standards, guidelines, MOUs, regulations an d permitting processes applicable at that time.

Table G-1
Physical Properties for Drinking Water

Property	Unit	Permissible Level	Maximum Level(1)
Turbidity	NTU	1	5
Color	True Color Units	10	15
Taste	-	Edible for most people	-
Odor	-	Acceptable for most people	-

(1) In the absence of a public water source of better quality.

Table G-2
Substances and Properties that Affect the Taste of Drinking Water

Property	Unit	Permissible Level	Maximum Level(2)
Hydroxide	Ph	6.5-8.5	-
Total Dissolved Solids (TDS)	mg/liter	500	1500
Total Hardness (TH)	mg/liter	300	500
Chemical Detergents (MBAS)	mg/liter	0.2	0.5
Ammonium (NH_4)	mg/liter	0.5	0.5
Aluminum (Al)	mg/liter	0.1	0.2
Manganese (Mn)	mg/liter	0.1	0.2
Iron (Fe)	mg/liter	0.3	1.0
Copper (Cu)	mg/liter	1.0	1.5
Zinc (Zn)	mg/liter	3.0	5.0
Sodium (Na)	mg/liter	200	400
Chloride (Cl)	mg/liter	200	500
Sulfates (SO_4)	mg/liter	200	500

(2) In the absence of a public water source of better quality.

Table G-3 Non-Organic Chemical Substances that have an Effect on Public Health			
Chemical Substance	**Unit**	**Permissible Level**	**Maximum Level(3)**
Arsenic (As)	mg/liter	0.01	-
Lead (Pb)	mg/liter	0.01	-
Cyanide (CN)	mg/liter	0.07	-
Cadmium (Cd)	mg/liter	0.03	-
Chrome (Cr)	mg/liter	0.05	-
Barium (Ba)	mg/liter	1.5	-
Selenium (Se)	mg/liter	1.5	-
Boron (B)	mg/liter	2.0	-
Mercury (Hg)	mg/liter	0.002	-
Silver (Ag)	mg/liter	0.1	-
Nickel (Ni)	mg/liter	0.07	-
Antimony (Sb)	mg/liter	0.005	-
Fluoride (Fl)	mg/liter	2.0	-
Nitrite (NO_2)	mg/liter	2.0	-
Nitrate (NO_3)	mg/liter	50	70
(3) In the absence of a public water source of better quality.			

Table G-4 Organic Pesticides that have an Effect on Human Health		
Chemical Substance	**Unit**	**Permissible Level**
Endrin	micrograms/liter	2.0
Lindane	micrograms/liter	4.0
Heptachlor Epoxide and Heptachlor	micrograms/liter	0.03
Aldrin	micrograms/liter	0.03
Dieldrin	micrograms/liter	0.03
2-4 D	micrograms/liter	90
DDT	micrograms/liter	2.0
2-4-5T	micrograms/liter	9.0
Total of above	micrograms/liter	100

Table G-5 Organic Contaminants/Pollutants in Drinking Water		
Chemical Substance	**Unit**	**Permissible Level**
Benzene	Micrograms/liter	10.0
Tetrachloro ethylene (PCE)	Micrograms/liter	5.0
Trichloro ethylene (TCE)	Micrograms/liter	5.0
Ethylbenzene	Micrograms/liter	500
Xylene	Micrograms/liter	700
Toluene	Micrograms/liter	300

Table G-6 Byproducts of the Sanitization/Disinfection Process		
Substance	**Unit**	**Permissible Level**
Total Trihalomethenes (TTHM)	mg/liter	0.15
Chlorite (ClO_2)	mg/liter	0.8
Free Chloride Surplus	-	When chloride is used to disinfect water, the water in the distribution network should contain not less than 0.2 mg/liter of free chloride surplus and not more than 1 mg/liter 15 minutes after adding the chloride to the water. Generally speaking, 15 minutes should lapse after the disinfection process before the disinfected water reaches the first consumer.

Table G-7 Radioactive Materials in Drinking Water		
Radioactive Material	**Unit**	**Standard Level for Radioactive Properties**
Alpha Radionuclides excluding Radon	Biquarel/liter	0.5
Beta Radionuclides excluding Tritium and Carbon 14	Biquarel/liter	1.0

In addition to the above, the water shall be free of fecal coliforms, pathogenic parasites and infectious intestinal worms. The number of any stage of free-living organisms (Nematodes) shall not exceed 1 living organism per liter.

G.2 Raw Water Quality

The KAC WTP will be fed by raw water draw from the King Abdullah Canal (KAC). The KAC serves as an irrigation canal and raw water source for the existing Zai WTP. The Wehdeh WTP will be fed by raw water drawn from the Yarmouk River, which also contributes flow to the KAC. Both water sources are high in particulate matter and pathogens. They also contain nutrients that promote algae, including those that can cause taste and odor. The raw water also contains nematodes. The parameters of interest are listed in **Tables G-8** and **G-9**, respectively.

Table G-8 KAC Water Treatment Plant Raw Water Quality			
Parameter	**Unit**	**Average**	**Range**
Turbidity	NTU	149	4-32,775
TSS	mg/L	66	6-341
Color	CU	9	0-262
Odor	TON	11	2-40
Total Organic Carbon	mg/L	3.4	0.7-42.9
Temperature	°C	21	10-30
pH	Unit	8.3	7.2-8.8
Total Alkalinity	mg/L	194	110-490
Bicarbonate Alkalinity	mg/L	178	94-490
Calcium	mg/L as $CaCO_3$	149	76-576
Magnesium	mg/L as $CaCO_3$	137	0-294
NonCarbonate Hardness	mg/L as $CaCO_3$	106	0-512
Total Hardness	mg/L as $CaCO_3$	285	112-752
Aggressive Index	mg/L	13	12-43
Conductivity	µS/cm at 20°C	1034	383-2001
Dissolved Oxygen	mg/L	8	4.5-10.6
Aluminum	mg/L	12.9	0-151
Ammonia	mg/L	0.1	0-2.0
Bromide	mg/L	1.5	0.4-3.3
Chloride	mg/L	180	39-255
Chromium	Ppb	60	60
Cobalt	Ppb	50	50
Copper	Ppb	29.1	0.3-30.0
Fluoride	mg/L	0.5	0.2-1.2
Iron	mg/L	0.1	0-0.7
Manganese	Ppb	19.4	0.4-25.0
Nitrate	mg/L	8.0	1.9-46.6
Phosphate	mg/L	0.1	0-3.1
Potassium	mg/L	7.6	3.3-10.8
Sodium	mg/L	104.8	27.4-141
Sulfate	mg/L	64.9	27.6-160
TDS	mg/L	511	235-707
Total Solids	mg/L	651	359-1616
Zinc	mg/L	0	0-0.2

Table G-9 Wehdeh Water Treatment Plant Raw Water Quality			
Parameter	**Unit**	**Average**	**Range**
Turbidity	NTU	33	4-32,775
TSS	mg/L	NA	NA
Color	CU	15	1-60
Odor	TON	12	4-17
Total Organic Carbon	mg/L	4.6	1.4-10.2
Temperature	ºC	24	14-33
pH	Unit	8.3	8.0-8.8
Total Alkalinity	mg/L	250	124-320
Bicarbonate Alkalinity	mg/L	230	124-320
Calcium	mg/L as $CaCO_3$	155	80-280
Magnesium	mg/L as $CaCO_3$	152	60-228
NonCarbonate Hardness	mg/L as $CaCO_3$	62	0-320
Total Hardness	mg/L as $CaCO_3$	306	164-440
Aggressive Index	mg/L	13	12-13
Conductivity	µS/cm at 20ºC	1049	516-1567
Dissolved Oxygen	mg/L	8.1	6.7-10.4
Aluminum	mg/L	32.5	0-261
Ammonia	mg/L	0.1	0-0.6
Bromide	mg/L	1.2	1.0-1.3
Chloride	mg/L	128	58.2-216
Chromium	Ppb	60	60
Cobalt	Ppb	48.5	0.1-50
Copper	Ppb	30.6	1.7-126
Fluoride	mg/L	0.5	0.2-0.9
Iron	mg/L	0.1	0-0.4
Manganese	Ppb	18.0	1.9-20.0
Nitrate	mg/L	22.6	7.6-64
Phosphate	mg/L	0.9	0.2-2.6
Potassium	mg/L	7.4	4.4-11.7
Sodium	mg/L	106	38.6-157
Sulfate	mg/L	90	41-197
TDS	mg/L	575	294-860
Total Solids	mg/L	644	306-989
Zinc	mg/L	0.1	0-0.2

G.3 Treatment Train Alternatives

Treatment alternatives have been identified, taking into account experience at the Zai WTP, which serves Amman and takes raw water from the KAC downstream from the proposed NGWA KAC intake. The Zai WTP, its associated intake system, raw water conveyance system, and treated water conveyance system was constructed in the 1980s. Up until July 1998, the plant had performed well. However, following severe taste and odor events in July and August of 1998, several private consulting firms were asked to investigate and make recommendations on improvements to the system in order to prevent a repeat of the taste and odor events. This current study has been conducted with an understanding of these events and recommendations, and the improvements made and operation of the WTP since that time.

In developing a water treatment train, the multiple treatment capabilities of the different methods and materials should all be considered to both simplify and reduce the cost of facility construction and operation. The two most promising alternatives for treating the KAC and Al-Wehdeh surface waters are:

- Conventional filtration. This alternative would include oxidation, adsorption, coagulation, flocculation, sedimentation, granular media filtration and disinfection. This type of filter plant reduces particulate matter, pathogens, disinfection by-product precursors, and color.

- Membrane filtration. This alternative would include pretreatment, membrane filtration and disinfection. Depending upon the type of membrane, membrane filtration can be used for the removal of dissolved organics as well as particulates and color removal. Ultra-filtration (UF) and micro-filtration (MF) membranes remove particulate matter exceeding 0.01 and 0.1 microns in size, respectively. Pretreatment before membrane filtration is required to:

  1. Condition the feed water to allow membrane treatment to be effective; for example, using coagulants to create particles large enough to be removed by MF membranes.

  2. Modify the feed water to prevent membrane plugging, fouling and scaling to maximize the time between cleanings and to prolong membrane life.

G.3.1 Conventional Treatment

Conventional treatment at either WTP would consist of the processes described below, with the processes arranged as shown in **Figure G.1**. **Tables G-11** and **G-12** (placed after the text describing the processes) list the design criteria for the main process units and the chemical handling systems, respectively.

Oxidation

We recommend that both potassium permanganate ($KMnO_4$) and chlorine dioxide (ClO_2) be injected into the raw water transmission main at or near the two new raw water intakes. In combination, these two chemicals will break down more organic molecules in the raw water than if only one were used. This will allow the downstream water treatment processes to work more effectively and efficiently. The use of these chemicals should provide pathogen inactivation, color removal, taste and odor control, oxidation of inorganic compounds (e.g, iron and manganese) and organic chemicals, and inactivate algae, prevent aquatic growths from developing in the mains and eliminate potential taste and odor events from this source, inactivate nematodes, and minimize trihalomethane (THM) formation. There may be times during the year when it will not be necessary to add potassium permanganate.

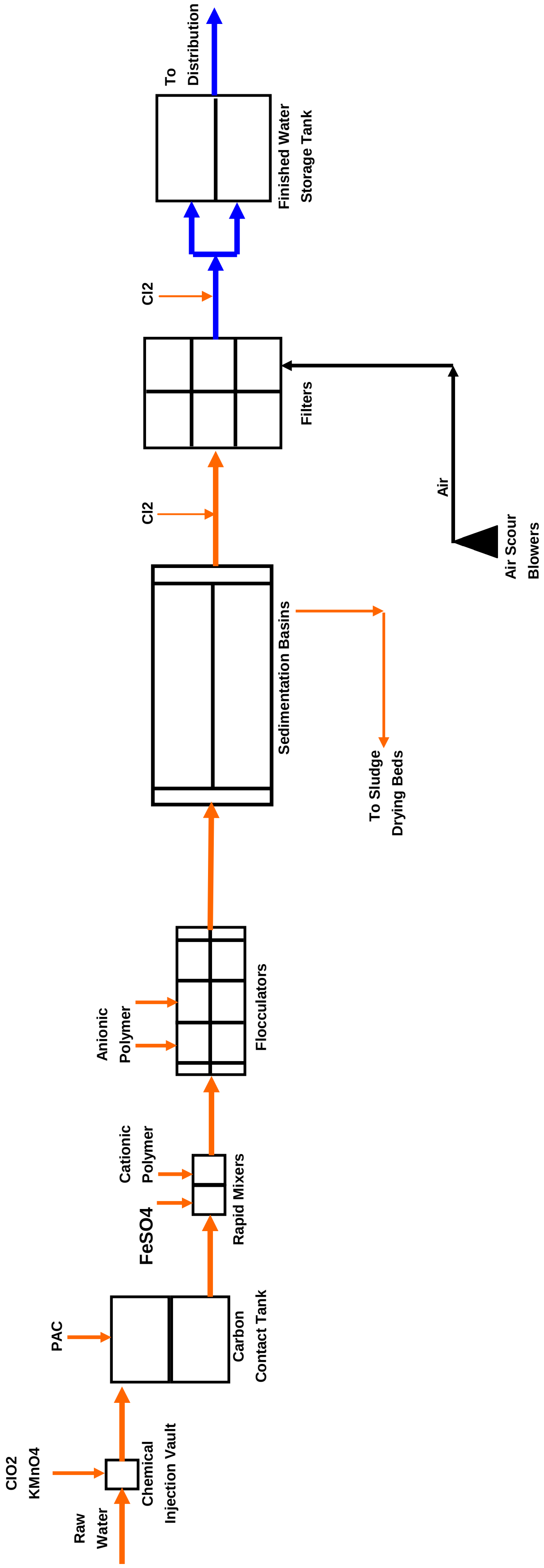


Figure G-1: Conventional Treatment System, Schematic Diagram for Wehdeh and KAC WTPs

Adsorption

We also recommend that powdered activated carbon (PAC) be fed to the raw water for taste and odor removal. A minimum contact time of 20 minutes should be provided before the coagulation process. Detention time could be provided in the raw water transmission main or in a contact tank or in a combination of both. PAC should not be applied upstream of the raw water pumps as it is very abrasive and would likely cause damage to pump impellers. PAC will adsorb dissolved organic materials such as natural organic matter (NOM), disinfection by-products (DBPs), and taste and odor compounds.

Coagulation

The relatively high pH of the two raw waters is optimum for an iron salt coagulant, and its use should result in less coagulant being used. Alum was utilized at the Zai WTP for many years. However, it is likely that excessive amounts of alum were required to lower the pH to the optimum value for coagulation. This could also result in a carryover of aluminum in the finished water. One method of preventing this is to lower the pH first with the use of an acid. However, this is expensive and dangerous chemical to handle. This will not be necessary with the use of an iron salt as coagulant. Another advantage of using an iron salt is that the resulting sludge dries easily. The two possible candidates are ferric sulfate ($Fe_2(SO_4)$) and ferric chloride ($FeCl_3$). Ferric sulfate is corrosive, but not as corrosive as ferric chloride. Ferric sulfate is a dry product and can be mixed and fed utilizing dry feed equipment similar to that used in the Zai WTP. Ferric chloride is a liquid product. Either chemical could be utilized for coagulation. Provisions should also be made to add a cationic polymer as a coagulant aid.

In order to make the coagulation process as efficient as possible, intense and rapid mixing of the coagulant into the water is required. Chemical mixing can be accomplished by mechanical devices in a dedicated basin or by in-line blenders.

Mechanical Mixers. Propeller (hydrofoil) or flat blade turbine-type mechanical mixers in a dedicated basin are the most common rapid mix system. Rapid mixers attempt to provide complete mixing by near-instantaneous blending throughout the entire basin. Typical design values for most mechanical rapid mix systems provide detention times of 30 to 60 seconds and G values of 300 to 600 sec^{-1}. Mechanical mixers are not normally provided with variable speed drives. If adjustments to energy input are necessary, they may be achieved by changing the mixer blades. Two-speed mixers have been used on numerous occasions. With this type of mixer, we recommend that two sets of rapid mix basins be used in parallel to allow for maintenance of one set while the second is in service. We also recommend that each set of basins contain two basins (called stages) in series, with the coagulant applied to the first stage and the coagulant aid applied to the second stage. To ensure complete mixing of each chemical, the chemical should be injected just below each mixer impeller.

In-Line Blenders. Advantages of this type of mixer are that it can approach nearly instantaneous dispersion of chemicals. In-line blenders operate at short detention times (less than one second) and at high G values (1,000 sec^{-1}) and can use an injection pump and nozzle or mechanical turbine mixer to provide the mixing intensity. A pumped system is one that draws a side stream from the main flow, boosts the pressure of the side stream, draws the chemical(s) into the side stream and injects the mixture into the main flow line through a nozzle pointing upstream against the flow. A mixed system is one that installs a mechanical mixer in a pipe with the chemical injection lines terminating near the mixer impeller. This type of mixer is difficult to maintain and is not recommended.

Because of simplicity and ease of maintenance, we recommend mechanical vertical turbine mixers in two-stage rapid mix basins.

Flocculation

Building optimum floc size requires gentle mixing in the energy gradient range of 20 to 80 sec^{-1} for a total of approximately 10 to 30 minutes. Flocculation can be achieved by hydraulic or mechanical devices. Hydraulic devices are used most often in small plants. Mechanical flocculators are preferred because of their greater flexibility in varying G values and also because they have low head loss.

Mechanical mixing by vertical turbine or horizontal paddle or reel-type mixers are universally used for this application. Given the use of vertical turbine mixers in the rapid mix basins, we recommend that this same type of mixer be used in the flocculation basins. This will minimize the number of spare parts that the plant will have to maintain in stock.

In order to provide flexibility of mixing and to allow for a wide range of energy to be applied to the flow, we recommend that flocculation tanks with three compartments in series be used. The flocculation compartments should be designed to create an over-under flow pattern to minimize short-circuiting. The mixing intensity in the compartments will be reduced as flow progresses. This will allow the operator to optimize the size of the floc for settling.

Provisions should be made to add an anionic or nonionic polymer to the first or second compartments in each tank to assist in producing a heavy floc for settling.

Sedimentation

Because of the high solids content of the raw water, conventional sedimentation is necessary. Long, rectangular basins have been used successfully for sedimentation for many years and are currently in successful use at the Zai WTP. When combined with the use of square flocculation basins, an efficient and cost effective tank layout is provided. For these reasons, they are recommended for this application.

The primary approach in designing conventional sedimentation basins is to select a design overflow rate for the maximum expected plant flow. This rate may be chosen based on all units being in service or on one unit being out of service, to allow for redundancy.

Overflow Rates. Hydraulic overflow rate is the primary design parameter for sizing sedimentation basins. This rate is defined as the rate of inflow (Q) divided by the tank surface area (A). Acceptable overflow rates vary with the nature of the settling solids, water temperature, and hydraulic characteristics of the sedimentation basin. Typical design overflow rates for sedimentation of solids produced through alum coagulation/flocculation are shown in **Table G-10**. For the ranges shown, higher rates are typical for warmer waters with heavier suspended solids. The design overflow rate for the Zai WTP is 36 $m^3/d/m^2$. This value falls within the range of typical overflow rates for this type of water and will be used for the design of the two new WTPs.

Table G-10 Overflow Rates	
Application	**($m^3/d/m^2$)**
Turbidity removal	32 to 48
Color and taste removal	24 to 40
High algae content	20 to 32

Basin Dimensions. Rectangular basins are generally designed to be long and narrow, with width-to-length ratios of 3:1 to 5:1. This shape is least susceptible to short-circuiting. Basin widths are often selected to match the requirements of the selected mechanical sludge collection equipment. Chain-and-flight collectors are limited to about a 6m width for a single pass, but it is possible to cover a wider basin in multiple passes. Traveling bridge collectors can be up to 30 m wide, limited only by the economics of bridge design and alignment.

Basin depths may be selected to provide a required detention time (though detention time is not a good design parameter) or may be selected to limit flow-through velocities and the potential for re-suspension of settled floc. Basins with mechanical sludge removal are usually between 3.0 and 4.5 m deep.

Inlet Zone. For long, narrow basins being fed directly from a flocculation basin, slots or port openings in the inlet wall are recommended to minimize short-circuiting. Head loss thorough the openings should be four to five times the velocity head of the approaching flow to ensure equal flow distribution. The *G* value through the openings should be equal to or less than that in the last flocculation compartment to minimize floc breakup.

Outlet Design. Outlet design is also critical in reducing short-circuiting and scouring of settled solids. Outlet designs have undergone a number of transformations. Basins were originally designed with end weirs. This type of outlet causes an increase in the horizontal and vertical velocity as floc is forced up the end wall to the weir, and the increased velocities cause considerable floc carryover by scouring settled floc and removing floc that has not had a time to settle.

In an effort to reduce velocities and carryover, long-finger weirs extending into the basin have been used. However, evaluation of the performance of this type of weir has indicated that bottom density currents still rise along the end wall causing floc carryover to the end of the weirs.

One approach to address this problem is to use a perforated end wall, similar to the inlet distribution wall, to maintain parallel hydraulic flow along the length of the basin. Velocity approaching the wall does not increase except near the ports because the entire basin cross section is used. As a result, velocity remains low along the floor, reducing the potential for scouring. Flow uniformity approaching the end wall helps to ensure that flow covers the entire basin surface to achieve the design overflow rate. We recommend that this approach be used.

Mechanical Solids Removal. Most modern sedimentation basins are designed to be mechanically cleaned using a variety of mechanisms, most of which are proprietary. These include systems that drag or plow sludge along the basin floor to hoppers and systems that rely on hydraulic or siphon action to withdraw solids. Traditional equipment was chain-and-flight made up of two strands of iron chain with wooden flights. Cast iron or steel wearing shoes were attached to the wooden flights to prevent the wood from wearing. A steel rail was attached to the wall for the flight to ride on as it looped back. New designs have been developed with high-molecular weight plastic or similar materials to replace the iron chain and sprocket. In addition, fiberglass flights have replaced the wooden boards, and plastic wearing strips are attached to the concrete floor and walls to replace the iron rails. These new systems are corrosion free and require little maintenance. However, when first installed, the plastic chain tends to stretch. This requires adjusting the chain tension one or two times during the first year of operation.

Another very popular system is the track-mounted hydraulic system. This system consists of a stainless steel collector pipe with orifices sized and spaced for proper sludge removal. The collector pipe is attached to a pneumatically actuated drive assembly that travels on a stainless steel guide rail running the length of the tank. Collector pipes are generally a maximum width of 6.0 to 7.5 m, and multiple units must be used to cover the width of wider tanks. The collector pipe is attached to a sludge discharge pipe in the tank wall. Options to the pneumatically driven collectors include continuous stainless steel tapes or chains, powered by a motor mounted at the top of one end of the basin that pull the collector pipe back and forth along a bottom–mounted rail.

The Zai WTP utilizes and has had success with a track-mounted hydraulic system for sludge removal. Therefore, we recommend that a similar system be installed in the two new WTPs.

Filtration

High-rate granular media filtration is the heart of any conventional water treatment plant. A number of interrelated components, including pretreatment, are involved in the overall design of a high-rate granular media filtration system. The filtration-related components include:

- Filter media
- Filtration rates
- Depth of filter box
- Filter operational control
- Filter media washing
- Filter arrangement
- Underdrain system
- Filter performance monitoring
- Auxiliaries

Filter Media. In drinking water applications, the most commonly used granular filter media are natural silica sand, crushed anthracite coal, and granular activated carbon (GAC). Selecting appropriate filter media involves a number of design decisions concerning raw water quality, pretreatment, and desired filtered water quality. Filter media cleaning requirements and underdrain system options depend on the filter configuration and filter media selected.

The Zai WTP has dual-media filters, containing beds with 600 mm of anthracite coal over 300 mm of filter sand supported by 300 mm of multi-layered gravel. The filters were originally fitted with an auxiliary surface wash system. However, this system was replaced recently by an air scour system which is more effective in cleaning the filters. The filters have performed adequately in removing suspended solids and organic matter not removed by the sedimentation process.

Assuming the pretreatment outlined above, we recommend that the filters in the two new WTPs be fitted with dual media of the same type, effective size and depth. Should raw water quality deteriorate significantly in the future or the taste and odor events experienced in July-August 1998 occur more frequently, it would be more effective to install GAC filter media in lieu of the dual media to ensure taste and odor control.

Filtration Rates. Dual-media filters operate successfully at rates from 120 to 320 L/min/m^2. The filters at the Zai WTP are designed for a filtration rate of 160 L/min/m^2 and have operated at this rate without difficulty. This filtration rate is well within the acceptable range and is recommended for the new gravity filters in the two new WTPs.

Depth of Filter Box. We recommend that the filter box be of adequate depth to allow for the installation of at least 900 mm of filter media and the associated support gravel and underdrain system. This will allow for increasing the depth of the filter media in the future to accommodate a larger effective size.

Filter Operational Control. Control of the filtration process is critical to successful operation. Filter control may be predicated either on head loss through the filter bed or on the rate of filtration. In either case, a smooth transition during changes in filtration rate is highly desirable.

We recommend constant-rate with rate-of-flow control. With this type of control, water levels in all the filters and the filter influent channel are maintained at a constant level. Plant flow is proportioned equally among the operating filters by means of a flow-measuring device (e.g., venturi meter) and modulating valves incorporated in the effluent piping of each filter. As the water level in the influent channel rises or falls because of filter media clogging, filters being taken out of service for washing or being placed back into service, or variations in the plant flow, a level element in the filter influent channel signals this movement to the controller which, in turn, modulates the flow through the operating filters.

Filter Media Washing. As the amount of solids retained in the filter media increases, bed porosity decreases. At the same time, head loss through the bed and shear on captured floc increase. Before the head loss builds to an unacceptable level or turbidity breakthrough occurs, washing is required to clean the filter media. Failure to clean the media adequately can lead to a multitude of problems. Initially, mud balls form and accumulate in the bed, causing problems. This can then lead to cracks forming in the filter media and short-circuiting of the bed during filtration, with subsequent decline in filtered water quality. To prevent this from happening, a robust filter media washing system should be utilized. We strongly recommend that an auxiliary air scour system be installed in conjunction with an upflow water wash.

The wash water source may be bled from the high-service pumps, direct pumping from a wet well, or gravity flow from a separate elevated storage tank. Bleeding flow from a high-service discharge main results in energy loss because of the pressure reduction required before washing. Direct pumping is very common. However, it requires a pump with a relatively large capacity which impacts the size of the electrical system as well as electrical demand charges. Gravity flow from an elevated storage tank is preferred in this instance because it permits pumping at a low rate. The wash water flow rate is measured and controlled by a venturi meter and rate control valve, respectively. This approach has been used successfully at the Zai WTP.

Air scour alone followed by high-rate water wash can be applied to dual media, because bed stratification occurs during the water wash. This method has been used with air scour rates of 0.6 to 1.5 $m^3/min/m^2$ followed by high-rate water wash at 37 to 56 m/h. A constant speed air scour blower will be installed to provide the air scour at each of the two new WTPs.

The wash water system will be designed to wash one filter at a time, and to wash four filters in a 24 hour period. Wash water will be collected in a recovery tank, from which it will be pumped to the head of the WTP.

Filter Arrangement. Gravity filters can be configured in a number of ways in the overall plant layout. It is important to develop a layout that is the least costly and is operationally optimized in terms of length-to-width ratio.

Filters are normally placed next to each other along one or both sides of a pipe gallery. This approach provides the most compact arrangement and simplifies filter operation and maintenance. From a cost point of view, one filter is the most ideal. Practically, however, four filters are the minimum number that should be used to allow for filter washing and maintenance.

The size of individual filters is determined by plant capacity, filtration rate, and the number of filters desired. Hydraulic considerations and the effect of removing a filter from service limit maximum filter size. Additional considerations include the maximum area to which wash water or air can be evenly distributed and the maximum length of wash water collection troughs. Large filters may be divided into two sections using a central gullet, permitting half the filter to be washed at a time.

Underdrain System. An underdrain system has two purposes; to collect water that passes through the filter media and to distribute wash water and air (if used) uniformly across the filter bed. Support gravel is required when openings in the underdrain system are larger than the filter medium directly above it. Although the support gravel does not contribute to particulate removal, it aids in distributing wash water. For this reason, it should be considered part of the underdrain system.

Currently, there are two types of underdrain systems that allow for both water and air backwashing. They are blocks and false bottoms. Both types of underdrain systems are suitable for the two new WTPs.

A commonly used block underdrain consists of vitrified clay blocks with 6 mm diameter dispersion orifices located across the top of each block. Support gravel is required for this type of underdrain. This type of underdrain is suitable only for water washing. However, auxiliary air scour may be provided by adding an air piping grid at the filter medium-gravel interface. Another type of block underdrain is designed for concurrent air/water wash. The blocks are constructed of polyethylene and consist of a primary feeder lateral (lower) and a secondary compensating lateral (upper). Small control orifices open from the flow through the feeder lateral and rise to discharge from the control orifices into the compensating lateral. The triangular shape of the primary lateral distributes incoming wash water and air uniformly along its length. Support gravel is typically used with this type of underdrain, graded in an hourglass configuration. As a replacement for support gravel, an integral media support (IMS) cap made of plastic beads sintered together may be installed on top of the plastic block underdrain. Use of the IMS cap allows for a reduction in the filter box depth.

One of the most widely used false-bottom underdrains is constructed of precast or cast-in-place reinforced concrete penetrated by nozzles and supported on concrete sills or columns. Fine openings in the nozzles eliminate the need for support gravel which reduces filter box depth. The nozzles are equipped with plunge pipes for air wash and are usually constructed of plastic or stainless steel.

Filter Performance Monitoring. Turbidity is the most common measure of filter performance. Each filter's effluent turbidity should be monitored and continuously recorded using an on-line turbidimeter. Turbidity measurement is sometimes used to automatically initiate a filter wash cycle or to activate an alarm whenever the filter effluent reaches a preset maximum turbidity level.

Particle counting is rapidly gaining acceptance to monitor filter performance. Particle counters are on-line instruments that can quantify and size particles in water by light-scattering techniques. Particles ranging in size from 1 to 500 μm can be quantified. This is useful in determining the log removal of particles in the *Giardia* and *Cryptosporidium* size ranges.

Auxiliaries. Wash water troughs are suspended at even spacing above gravity filter beds to provide uniform removal of wash water during backwashing. These same troughs also distribute influent flow uniformly across the filter media's top surface. This limits horizontal travel required and equalizes static head on the underdrain system. Troughs are usually made of fiberglass, stainless steel or concrete with U or V-shaped bottoms to prevent solids accumulation.

A filter-to-waste system should be included in the new WTPs. Typically, this consists of a separate filter-to-waste line that collects effluent water from a filter just after it has been backwashed and placed back into service. This line may discharge either to a sump or tank, where it is then pumped back to the filter influent channel or the head of the WTP. In this case, the filter-to-waste shall discharge to the recovery tank which will be sized to handle 30 minutes of filter-to-waste volume at a filtration rate of 10 m/hr.

Provisions should be made to add chlorine periodically to the filter influent channel to control biological growths in the filter media.

Disinfection

A significant amount of pre-disinfection will be provided through the addition of chlorine dioxide and potassium permanganate to the raw water. However, it will be necessary to apply a final disinfectant to the water after filtration to ensure that all remaining pathogens are inactivated and to provide a disinfecting residual throughout the distribution system. Because it is less expensive and because chlorine dioxide can cause taste and odor problems brought about by reformed ClO_2 in the distribution system, chlorine is recommended to provide final disinfection.

Chlorine should be applied to a finished water storage tank or clearwell, baffled to prevent short-circuiting. To inactivate/remove viruses and *Giardia*, the *Recommendations of the Higher Committee for Water Quality* of July 2001 for Group 3 raw waters has specified 4 log (99.99%) inactivation/removal for *Giardia* and 5 log (99.999%) for viruses. A 2.5 log (99.7%) removal credit for *Giardia* and 2 log (99.0%) removal credit for viruses can be taken for an efficient conventional water treatment plant with granular media filters. The remaining *Giardia* and virus log requirements (1.5 and 3 log removals, respectively) must be implemented by disinfectant inactivation.

The USEPA has published Giardia and virus inactivation tables for chlorine that are applicable to the two WTPs under study; i.e., pH <= 9.0, the worse case water temperature of 10° C and a chlorine concentration of 1.0 mg/L. From these tables, *Giardia* inactivation requires a CT (concentration x time) of 117 mg/L-min. With a chlorine residual of 1.0 mg/L, a contact time (T_{10}) of 117 minutes needs to be provided at the design flow. Assuming a typical baffling system, the short-circuiting factor (T_{10}/t) will be about 0.5. Therefore, the hydraulic residence time that needs to be provided in the storage tank is 234 minutes.

We recommend that two tanks or a tank with two compartments be used, and that each tank or compartment have the volume to meet the required hydraulic residence time. This will allow one tank or compartment to be removed from service for maintenance and still maintain the required CT of 117 mg/L-min.

Table G-11
Design Criteria for Conventional Treatment

Item	Units	KAC WTP	Wehdeh WTP
Plant Capacity	m^3/hr	600	4,110
Oxidation		In Raw Water Pipeline	In Raw Water Pipeline
Adsorption			
Number of Contact Tanks		1	1
Detention Time	min	30	30
Volume of Contact Tank	m^3	300	2,055
Size of Tank	m	4 x 16.7 x 4.5 swd	10 x 45.7 x 4.5 swd
Coagulation			
Configuration		1 train w/ 2 basins in series	2 trains w/ 2 basins in series
Number of Vertical Turbine Mixers		2	4
Detention Time, each Basin	sec	60	30
Volume, each Basin	m^3	10.0	18.0
Size, each Basin	m	1.5 x 1.5 x 4.5 swd	2.0 x 2.0 x 4.5 swd
Energy Gradient, *G*, first stage	Sec^{-1}	600	600

Energy Gradient, *G*, second stage	Sec^{-1}	300	300
Flocculation			
Configuration		4 trains w/ 3 compartments in series	8 trains w/ 3 compartments in series
Detention Time, each Compartment	min	10	10
Volume, each Compartment	m^3	25	85.6
Size, each Compartment	m	2.35 x 2.35 x 4.5 swd	4.35 x 4.35 x 4.5 swd
Energy Gradient, *G*, first stage	Sec^{-1}	80	80
Energy Gradient, *G*, second stage	Sec^{-1}	50	50
Energy Gradient, *G*, third stage	Sec^{-1}	20	20
Sedimentation			
Number of Basins		2	4
Overflow Rate	$m^3/d/m^2$	36	36
Size, each Basin	m	5.0 x 40.0 x 4.5 swd	9.0 x 76.1 x 4.5 swd
Volume, each Basin	m^3	900	3082
Detention Time, each Basin	min	180	180
Horizontal Velocity	m/min	0.22	0.42
Filtration			
Number of Filters		4	6
Size, each Filter	m	3.2 x 6.4	6.5 x 13
Surface Area, each Filter	m^2	20.5	84.5
Filtration Rate, all filters in service	m/hr	7.3	8.1
Filtration Rate, one filter out of service	m/hr	9.8	9.7
Filter Profile Anthracite Filter Sand Gravel (if needed)	 mm mm mm	 600 300 300	 600 300 300
Maximum Air Scour Rate	$m^3/m^2/min$	1.2	1.2
Number of Blowers		1	2 (1 standby)
Capacity, each Blower	m^3/min	24.6	101.4
Maximum Wash Water Rate	m/hr	60	60
Average Wash Water Rate	m/hr	40	40
Volume of Wash Water per Wash of 15 Minute Duration	m^3	205	845
Number of Wash Water Storage Tanks		1	1
Usable Volume of Wash Water Storage Tank	m^3	410	1,690
Diameter of Storage Tank	m	8.6	17.5
Depth of Storage Tank Total Usable	 m m	 8.5 7.0	 8.5 7.0

Number of Wash Water Pumps		2 (1 standby)	2 (1 standby)
Capacity, each Pump, to refill Storage Tank in 180 min	m^3/min	2.3	9.4
Filter-to-Waste Rate	m/hr	10	10
Volume of Filter-to-Waste of 30 Minute Duration	m^3	102.5	422.5
Number of Recovery Tanks (for waste wash water and filter-to-waste)		1	1
Volume of Recovery Tank	m^3	512.5	2,112.5
Size of Recovery Tank	m	7 x 16.3 x 4.5 swd	15 x 31.3 x 4.5 swd
Number of Recovery Pumps		2 (1 standby)	2 (1 standby)
Capacity, each Pump, to recycle in 360 min	m^3/min	1.4	5.7
Disinfection			
Configuration of Finished Water Storage Tank		1 tank w/ 2 compartments	1 tank w/ 2 compartments
Hydraulic Detention Time, each Compartment	min	117	117
Volume, each Compartment	m^3	1,170	8,015
Size, each Compartment	m	16.1 x 16.1 x 4.5 swd	42.2 x 42.2 x 4.5 swd
Chemicals (both WTPs)			
		Average	**Maximum**
Chlorine Dioxide	mg/L	1.5	3
Potassium Permanganate	mg/L	3	3
Powdered Activated Carbon	mg/L	15	30
Ferric Sulfate	mg/L	15 summer; 25 winter	40
Cationic Polymer	mg/L	1	2
Anionic or Nonionic Polymer	mg/L	0.02	0.05
Chlorine Chlorine Dioxide Filter Cleaning Final Disinfection	 mg/L mg/L mg/L	 1 1 1	 2 5 2
swd = side water depth			

Table G-12
Design Criteria for Chemical Handling Systems for Conventional Treatment

Item	Units	KAC WTP	Wehdeh WTP
Chlorine Dioxide (generated on site by combining sodium chlorite and chlorine)			
Application Point		Raw Water Transmission Main	
Design Capacity	kg/day	43.1	295.1
Delivered Chemical		Liquid	
Number of Generators		2 (1 standby)	

Capacity, each Generator	kg/hr	2.5	18.9
Sodium Chlorite (used to generate chlorine dioxide)			
Application Point		Chlorine Dioxide Generator	
Design Capacity	kg/day	57.8	395.4
Delivered Chemical		Liquid, 25%, Bulk	
Type of Storage Tanks		Vertical, cylindrical, closed top, FRP	
Number of Tanks		2	
Volume, each Tank, for 30 day storage time	m^3	7.6(1)	11.4
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	8.2	56.1
Potassium Permanganate			
Application Point		Raw Water Transmission Main	
Design Capacity	Kg/day	43.1	295.1
Delivered Chemical		Crystals, 97%, Drums	
Bulk Density	Kg/m^3	1,450	
Type of Feeder		Volumetric	
Number of Feeders		1	2 (1 standby)
Capacity, each Feeder	L/hr	1.7	8.5
Solution Strength	%	1	
Type of Storage Tank		Vertical, cylindrical, open top, FRP	
Number of Tanks		1	2 (1 standby)
Volume, each Tank, for 24 hr detention time	m^3	0.28	1.32
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	182	1,230
Powdered Activated Carbon			
Application Point		Carbon Contact Tank	
Design Capacity	kg/day	430	2,950
Delivered Chemical		Powder, 100%, Bags	
Bulk Density	kg/m^3	340	
Type of Feeder		Volumetric	
Number of Feeders		1	2 (1 standby)
Capacity, each Feeder	L/hr	62	425
Solution Strength		20	
Type of Storage Tank		FRP	
Number of Tanks		1	2
Volume, each Tank, for 1 hr detention time		0.4	1.9
Type of Metering		Eductor	
Number of Eductors		2 (1 standby)	
Capacity, each Eductor	L/hr	310	2,125
Ferric Sulfate			
Application Point		Rapid Mix Basins, First Stage	

Design Capacity	kg/day	575	3,935
Delivered Chemical		Granular, 68 or 76% $Fe_2(SO_4)_3$, Bags	
Bulk Density	kg/m³	1,025	
Type of Feeder		Volumetric	
Number of Feeders		2 (1 standby)	
Capacity, each Feeder	L/hr	28.3	170
Solution Strength	%	10	
Type of Storage Tank		Type 316 Stainless Steel	
Number of Tanks		2	
Volume, each Tank, for 1 hr detention time	m³	0.4	1.9
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	3 (1 standby)
Capacity, each Pump	L/hr	240	820
Cationic Polymer			
Application Point		Rapid Mix Basins, Second Stage	
Design Capacity	kg/day	28.8	196.7
Delivered Chemical		Liquid, 100%, Bulk	
Type of Storage Tank		Vertical, cylindrical, closed top, FRP	
Number of Tanks		1	2
Volume, each tank, for 30 day storage time	m³	7.6(4)	7.6
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	3 (1 standby)
Capacity, each Pump	L/hr	1.2	3.9
Anionic or Nonionic Polymer			
Application Point		Flocculation Basins, First and Second Stages	
Design Capacity	kg/day	0.7	4.9
Delivered Chemical		Granular, 100%, Bags	
Bulk Density	kg/m³	750	
Type of Feeder		Volumetric	
Number of Feeders		1	
Capacity, each Feeder	L/hr	22.6	22.6
Solution Strength	%	0.5	
Type of Storage Tank		FRP	
Number of Tanks		1	
Volume, each Tank, for 24 hr detention time	m³	0.25	1.14
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	3 (1 standby)
Capacity, each Pump	L/hr	6	20.5
Chlorine (used to generate chlorine dioxide)			
Application Point		Chlorine Dioxide Generators	
Design Capacity	kg/day	28.8	196.7
Delivered Chemical		Liquid, Ton Containers	

Type of Chlorinator		Gas	
Number of Chlorinators		2 (1 standby)	
Capacity, each Chlorinator	kg/day	227	227
Chlorine (used for filter cleaning and final disinfection)			
Application Points		Filter Influent and Finished Water Storage Tank Influent	
Design Capacity	kg/day	71.9 (filter cleaning) 28.8 (final disinfection)	492 (filter cleaning) 196.7 (final disinfection)
Delivered Chemical		Liquid, Ton Containers	
Type of Chlorinator		Gas	
Number of Chlorinators		3 (1 standby)	3 (1 standby) (5)
Capacity, each Chlorinator	kg/day	227	227
(4) Minimum volume to allow for truck delivery. (5) Standby unit to be used to provide a total of 454 kg/day for filter cleaning.			

Table G-13 lists the estimated capital costs using the conventional treatment processes at the two WTPs.

Table G-13: Estimated Costs, Conventional Treatment Processes

Item	Units	KAC WTP	Wehdeh WTP
MOBILIZATION AND DEMOBILIZATION		$ 150,000	$ 450,000
SITE WORKS		$ 388,000	$ 1,615,000
Land Cost	LS	$ 30,000	$ 200,000
Site Grading	LS	$ 5,000	$ 50,000
Site Structural Works	LS	$ 25,000	$ 100,000
Roads, parking and paved areas	LS	$ 54,000	$ 180,000
Landscaping (Tree plantation)	LS	$ 24,000	$ 80,000
Yard piping	LS	$ 200,000	$ 800,000
Yard Electrical Power and Lighting	LS	$ 15,000	$ 75,000
Yard Instrumentation/Control Cables and Equipment	LS	$ 10,000	$ 30,000
Fencing and Gates	LS	$ 25,000	$ 100,000
BUILDINGS		$ 290,000	$ 777,500
Admin building including control room and lab	LS	$ 100,000	$ 200,000
Chemical building (CIO2, MnO4, Pac)	LS	$ 125,000	$ 400,000
Chlorine building	LS	$ 40,000	$ 115,000
Blower room	LS	$ 25,000	$ 62,500
PROCESS UNITS Civil Works		$ 924,291	$ 4,000,974
Inlet Structure	LS	$ 15,000	$ 50,000
Adsorption Tank	LS	$ 65,013	$ 241,665
Coagulation basin	LS	$ 12,500	$ 32,200
Flocculation Tank	LS	$ 112,434	$ 428,388
Sedimentation Tank	LS	$ 238,400	$ 1,147,300
Filters	LS	$ 77,864	$ 279,750
Filters Wash Tanks	LS	$ 47,530	$ 195,917
Filters Recovery Tanks	LS	$ 58,055	$ 162,485
Finshed Water Tanks	LS	$ 229,264	$ 1,036,821
Sludge Drying Beds	LS	$ 68,232	$ 426,447
PROCESS Equipment		$ 2,383,250	$ 6,919,000
Rapid Mixers/Flocculators	LS	$ 155,250	$ 316,250
Sludge Removal Equipment	LS	$ 448,500	$ 1,610,000
Filter Underdrains/Troughs	LS	$ 143,750	$ 690,000
Air Scour Blowers	LS	$ 57,500	$ 230,000
Wash Water Pumps	LS	$ 28,750	$ 63,250
Recovery Pumps	LS	$ 34,500	$ 46,000
Filter Media	LS	$ 74,750	$ 437,000
Metering Pumps	LS	$ 40,250	$ 63,250
Chlorinators	LS	$ 11,500	$ 28,750
Chemical Storage Tanks	LS	$ 28,750	$ 40,250
Dry Feed Systems	LS	$ 230,000	$ 425,500
Chlorine Dioxide Generators	LS	$ 11,500	$ 28,750
Instrumentation Work	LS	$ 278,250	$ 735,000
Electrical Work	LS	$ 840,000	$ 2,205,000
Subtotal		**$ 4,135,541**	**$ 13,762,474**
Contractors OH&Profit 35%		**$ 1,447,439**	**$ 4,816,866**
Contingencies 20%		**$ 1,116,596**	**$ 3,715,868**
Total Estimated Cost		**$ 6,699,577**	**$ 22,295,207**

G.3.2 Membrane Treatment

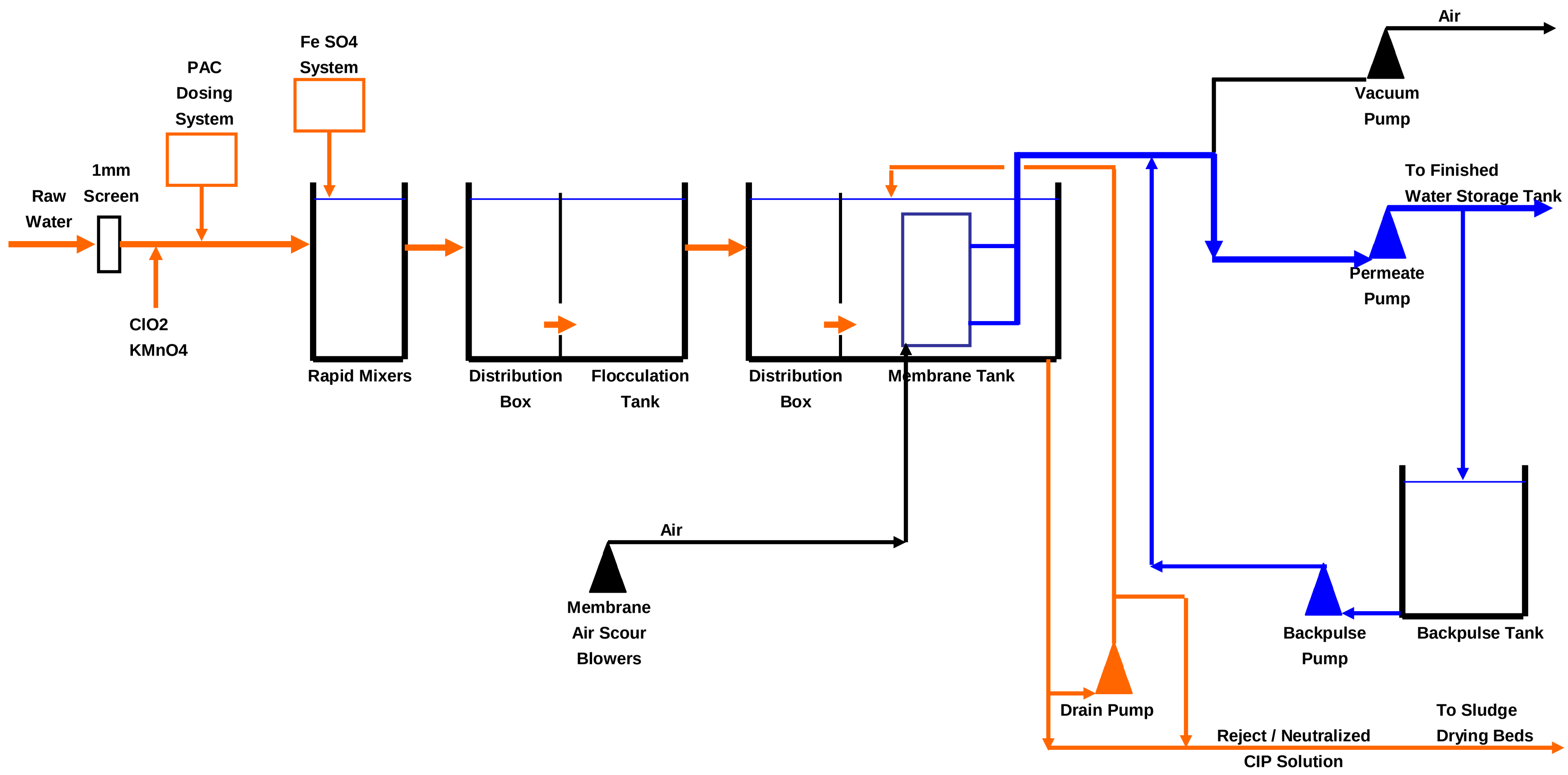
There are two types of membranes that are commonly used in water treatment. They are pressure and vacuum driven membranes. Pressure membranes are commonly used in treating high quality water sources (e.g., groundwater) for desalting, softening, dissolved organics and color removal, and particulate removal. They are also now used to remove *Giardia* cysts, *Cryptosporidium* oocysts, and particles from surface waters and to treat backwash return waters from conventional water treatment plants. When treating surface waters, they typically will require significant pretreatment in order to lessen the load that is applied to the membranes. On the other hand, immersed membranes can be utilized in treating poor quality surface waters that are high in solids and organic matter with only minimal pretreatment. This type of membrane is most applicable to this application. Of the two types of membranes, one is an ultrafiltration membrane (ZeeWeed® 500 Series) manufactured by Zenon Environmental Corporation and the other is a microfiltration membrane (CMF-S) manufactured by U.S. Filter/MEMCOR®. Both are designed on the principle of immersing hollow fiber membranes in a tank filled with the source water and drawing the water through the membranes using a low vacuum. A process schematic diagram for membrane treatment is shown on **Figure G-2**.

G.3.2.1 Ultra-filtration Membranes

ZeeWeed 500 Series hollow fiber membranes have a nominal pore size of 0.04 microns. The small pore size excludes particulate matter including *Giardia* cysts and *Cryptosporidium* oocysts from the treated water. Additionally, some viruses are removed by a combination of adsorption onto the solids in the process tank and by direct size exclusion. ZeeWeed membranes can achieve ≥ 4 log removal of *Giardia* cysts and *Cryptosporidium* oocysts and ≥ 2.0 log removal of viruses.

The membranes operate under a vacuum created within the hollow membrane fibers by a permeate pump. Treated water is drawn through membrane pores and enters the inside of the hollow fibers. Water then flows through the permeate pump to the finished water storage tank or directly to the distribution system.

Figure G-2: Membrane Treatment System, Schematic Diagram for Wehdeh and KAC WTPs



ZeeWeed membranes are manufactured in discrete units called "modules." The modules are then grouped together in what are termed "cassettes." A train is a discrete unit consisting of multiple cassettes that are manifolded together and connected to a common permeate pump. The cassettes are lowered into a concrete tank that is filled with the source water. The design of the permeate header allows groups of cassettes to be isolated for the purpose of performing membrane integrity hold tests.

In addition to particulate (turbidity) removal and pathogen removal, the membranes are highly effective in removing color, total organic carbon (TOC), and dissolved organic carbon (DOC) when combined with coagulant addition. The coagulant adsorbs dissolved organics that would otherwise pass through the membranes, but are removed once adsorbed onto a particle. Coagulant is injected into the raw feed water to allow the formation of pin-sized floc particles that only need to be larger than the membrane pores for removal by the membranes. In this case, pretreatment will require the addition of chlorine dioxide for oxidation, PAC for adsorption, and ferric sulfate for coagulation with a minimum flocculation time of 8 to 10 minutes.

Air is periodically (10 seconds on; 10 to 40 seconds off) introduced at the bottom of the membrane modules to create turbulence along the membrane surface. The rising air bubbles scour and clean the outside of the membranes fibers allowing them to operate at a higher flux rate, thus maximizing membrane performance. The aeration also oxidizes iron and organic compounds, resulting in a treated water quality that is better than that provided by direct ultrafiltration alone.

Flow through the membranes is monitored, as is the vacuum pressure applied. As water is drawn through the membranes during filtration, solids are removed at the membrane surface and accumulate in a manner similar to a conventional granular media filter. The effect of solids accumulation on the membrane surface is to restrict flow through the membranes, eventually reaching a point where cleaning is required to maintain the design operating flux (i.e., permeability). Cleaning is achieved periodically by three separate and distinct steps:

- Reversing the flow through the membranes (termed "backpulsing") using permeate previously filtered by the membrane system and stored for this purpose. The design backpulse frequency is every 15 minutes for 30 seconds. Permeate and backpulse flows are measured by flow meters installed in the discharge of the permeate pumps.

- A "maintenance" cleaning will be accomplished once a day to restore part of the permeability and to lengthen the interval between "recovery" cleanings. To achieve this step, a membrane tank is isolated from service and sodium hypochlorite is dosed during a series of five backpulses at a concentration of 50 mg/L and allowed to soak for a few minutes. To assist in this soaking, the solution is recirculated with a recirculation pump. If chlorine residual remains after soaking, sodium bisulfite is fed to the recirculating solution to neutralize the hypochlorite. Sodium hydroxide is then added to the solution when recirculating to adjust the pH to meet the requirements for discharge. The solution is then discharged by gravity to a sewer or, if a sewer is not available, pumped to a truck for transport to a wastewater treatment plant.

- Once a month the membranes will require more aggressive cleaning to restore the flux rate, as backpulsing and maintenance cleanings alone are not adequate for this purpose.

This step is termed "recovery" cleaning. To achieve this step, a membrane tank is isolated from service and sodium hypochlorite and citric acid are dosed during a backpulse at concentrations of 2,000 and 8,000 mg/L, respectively. The membrane tank is then topped off to obtain concentrations of 250 and 1,000 mg/L, respectively, for these two chemicals. This solution is recirculated for about 5 hours with a recirculation pump. At the end of this period, sodium bisulfite is fed to the recirculating solution for approximately 15 minutes and used to neutralize the hypochlorite solution after a recovery clean. Sodium hydroxide is then added to the solution when recirculating to adjust the pH to meet the requirements for discharge. The solution is then discharged by gravity to a sewer or, if a sewer is not available, pumped to a truck for transport to a wastewater treatment plant.

After approximately ten years, the life of the membranes will have been reached and it will be necessary to replace them. This is an expensive undertaking and needs to be factored into the cost of a membrane plant.

Unlike pressure type membrane systems, immersed membrane systems do not generate reject water during the filtration process. Rather, water used for backpulsing the membranes is pumped into the membrane tank and is then drawn back through the membranes when the system is filtering.

To prevent solids from concentrating within the membrane tank, the tank is periodically drained by gravity and discharged to a sewer or solids handling system. The frequency of this "deconcentration" step is determined based on the desired recovery. The drain line is sized such that the tank can be drained quickly, typically within one minute. In order to minimize downtime, the tank must be refilled quickly as well.

On the average, eight percent of the influent flow to the membrane process will be lost due to the deconcentration step, and the maintenance and recovery cleaning steps. In other words, the "recovery rate" will be 92 percent. Therefore, the raw water pumps and pretreatment facilities, as well as the membrane facilities themselves, need to be oversized in order to achieve the design flows at the effluent end of the two treatment plants.

Due to the low pressure operation of the system, there is a tendency for dissolved air to be released from the water. To prevent the problems associated with air locks in the permeate piping and pumps, an air removal system is typically incorporated. The air removal system consists of an air separation column located at the end of the permeate collection header pipe. Any air released form the water collects at the high point in the air separation column and is automatically vented from the system by an air release valve located on the top of the column. The air release valve is connected to a vacuum pump that runs continuously.

The backpulse water storage tank is filled automatically with permeate during normal plant operation. When the level in the tank is low, permeate is automatically diverted into the tank which is equipped with a level transmitter.

Clarity of the treated water from each train is monitored continuously by online turbidimeters and particle counters. A membrane is a physical barrier and solids levels in the treated water are normally very low. An increase in turbidity or particle counts can indicate either a membrane failure or possibly a leaking or damaged pipe. To protect the integrity of the treated water and also to maintain the long-term operating performance of the membrane system, in the event of high turbidity or particle count the affected process stream will be automatically shut down. The source of particulate entry into the permeate can then be determined by bubble point tests to locate the place where the membrane has been compromised.

Disinfection

A significant amount of pre-disinfection will be provided through the addition of chlorine dioxide and potassium permanganate to the raw water. However, it will be necessary to apply a final disinfectant to the water after filtration to ensure that all remaining pathogens are inactivated and to provide a disinfecting residual throughout the distribution system. Because it is less expensive and because chlorine dioxide can cause taste and odor problems brought about by reformed ClO_2 in the distribution system, chlorine is recommended to provide final disinfection.

Chlorine should be applied to a finished water storage tank or clearwell, baffled to prevent short-circuiting. To inactivate/remove viruses and *Giardia*, the Jordanian Standard for Grade 3 raw waters has specified 4 log (99.99%) inactivation/removal for *Giardia* and 5 log (99.999%) for viruses. A 4 log (99.99%) removal credit for *Giardia* and 2 log (99.0%) removal credit for viruses can be taken for an efficient membrane water treatment plant. The remaining virus log requirements (3 logs) must be implemented by disinfectant inactivation. However, a minimum of 0.5 log inactivation for *Giardia* should be provided at all times.

The applicable USEPA Giardia and virus inactivation tables for chlorine have been applied to the two new WTPs; i.e., pH <= 9.0, the worse case water temperature of 10^o C and a chlorine concentration of 1.0 mg/L. From these tables, *Giardia* inactivation requires a CT (concentration x time) of 39 mg/L-min. With a chlorine residual of 1.0 mg/L, a contact time (T_{10}) of 39 minutes needs to be provided at the design flow. Assuming an average baffling system, the short-circuiting factor (T_{10}/t) will be about 0.5. Therefore, the hydraulic residence time that needs to be provided in the storage tank is 78 minutes.

We recommend that two tanks or a tank with two compartments be used, and that each tank or compartment have the volume to meet the required hydraulic residence time. This will allow one tank or compartment to be removed from service for maintenance and still maintain the required CT of 39 mg/L-min.

Tables G-14 and **G-15** list the design criteria for the main process units and the chemical handling systems, respectively.

Table G-14
Design Criteria for Ultra-filtration Membrane Treatment

Item	Units	KAC WTP	Wehdeh WTP
Plant Capacity (effluent)	m^3/hr	600	4,110
Design Recovery Rate	%	92	
Required Influent Flow	m^3/hr	652	4,468
Oxidation		In Raw Water Pipeline	
Adsorption			
Number of Contact tanks		1	
Detention Time	min	30	
Volume of Contact Tank	m^3	326	2,234
Size of Tank	m	4 x 18.1 x 4.5 swd	10 x 49.7 x 4.5 swd

Coagulation			
Configuration		1 train w/ 2 basins in series	2 trains w/ 2 basins in series
Number of Vertical Turbine Mixers		2	4
Detention Time, each Basin	sec	60	30
Volume, each Basin	m^3	10.8	18.9
Size, each Basin	m	1.55 x 1.55 x 4.5 swd	2.05 x 2.05 x 4.5 swd
Energy Gradient, *G*, first stage	sec^{-1}	600	
Energy Gradient, *G*, second stage	sec^{-1}	300	
Flocculation			
Configuration		2 trains w/ 2 compartments in series	4 trains w/ 2 compartments in series
Detention Time, each Compartment	min	5	5
Volume, each Compartment	m^3	27.0	93.2
Size, each Compartment	m	2.45 x 2.45 x 4.5 swd	4.55 x 4.55 x 4.5 swd
Energy Gradient, *G*, first stage	sec^{-1}	80	
Energy Gradient, *G*, second stage	sec^{-1}	50	
Membrane Filtration			
Number of Trains		4	10
Number of Cassettes, each Train		3	7
Total Number of Cassettes		12	70
Number of Modules, each Cassette		54	54
Total Number of Modules		648	3,780
Number of Spare Module Spaces, each Cassette		10	
Spare Space	%	16	
Surface Area, each Module	m^2	31.6	
Design Flux (nominal) All Trains One Train Off-line	 $m^3/m^2/day$ $m^3/m^2/day$	 0.70 0.94	 0.82 0.92
Number of Membrane Tanks		4	10
Volume (displaced), each Tank	m^3	48.5	104.0
Size, each Tank	m	6.85 x 3.05 x 3.45 swd	14.8 x 3.05 x 3.45 swd
Number of Membrane Air Scour Blowers		3 (1 standby)	
Capacity, each Blower	m^3/min	34.4	200.7

Number of Permeate Pumps		4	10
Capacity, each Pump	m^3/hr	163	447
Number of Vacuum Pumps		3 (1 standby)	
Number of Backpulse Tanks		1	
Number of Backpulse Pumps		2 (1 standby)	
Capacity, each Pump	m^3/hr	224	512
Number of Recirculation Pumps		2 (1 standby)	
Capacity, each Pump	m^3/hr	194	416
Disinfection			
Configuration of Finished Water Storage Tank		1 tank w/ 2 compartments	1 tank w/ 2 compartments
Hydraulic Detention Time, each Compartment	min	78	78
Volume, each Compartment	m^3	850	5,810
Size, each Compartment	m	13.7 x 13.7 x 4.5 swd	36 x 36 x 4.5 swd
Chemicals (both WTPs)			
		Average	**Maximum**
Chlorine Dioxide	mg/L	1.5	3
Potassium Permanganate	mg/L	3	3
Powdered Activated Carbon	mg/L	15	30
Ferric Sulfate	mg/L	15 summer; 25 winter	40
Sodium Hypochlorite			
Maintenance Clean	mg/L	50	50
Recovery Clean	mg/L	250	2,000
Citric Acid	mg/L	1,000	8,000
Sodium Bisulfite			
Maintenance Clean	mg/L	n/a	50
Recovery Clean	mg/L	n/a	250
Sodium Hydroxide			
Maintenance Clean	mg/L	n/a	20
Recovery Clean	mg/L	n/a	440
Chlorine			
Chlorine Dioxide	mg/L	1	2
Final Disinfection	mg/L	1	2
swd = side water depth n/a = not applicable			

Table G-15
Design Criteria for Chemical Handling Systems for Ultra-filtration Membrane Treatment

Item	Units	KAC WTP	Wehdeh WTP
Chlorine Dioxide (generated on site by combining sodium chlorite and chlorine)			
Application Point		Raw Water Transmission Main	
Design Capacity	kg/day	46.8	320.8

Delivered Chemical		Liquid	
Number of Generators		2 (1 standby)	
Capacity, each Generator	Kg/hr	2.5	18.9
Sodium Chlorite (used to generate chlorine dioxide)			
Application Point		Chlorine Dioxide Generator	
Design Capacity	kg/day	62.8	429.8
Delivered Chemical		Liquid, 25%, Bulk	
Type of Storage Tanks		Vertical, cylindrical, closed top, FRP	
Number of Tanks		2	
Volume, each Tank, for 30 day storage time	m^3	7.6(1)	11.4
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	8.9	61.0
Potassium Permanganate			
Application Point		Raw Water Transmission Main	
Design Capacity	kg/day	46.9	320.8
Delivered Chemical		Crystals, 97%, Drums	
Bulk Density	kg/m^3	1,450	
Type of Feeder		Volumetric	
Number of Feeders		1	2 (1 standby)
Capacity, each Feeder	L/hr	1.7	8.5
Solution Strength	%	1	
Type of Storage Tank		Vertical, cylindrical, open top, FRP	
Number of Tanks		1	2 (1 standby)
Volume, each Tank, for 24 hr detention time	m^3	0.28	1.32
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	198	1,337
Powdered Activated Carbon			
Application Point		Carbon Contact Tank	
Design Capacity	kg/day	467	3,207
Delivered Chemical		Powder, 100%, Bags	
Bulk Density	kg/m^3	340	
Type of Feeder		Volumetric	
Number of Feeders		1	2 (1 standby)
Capacity, each Feeder	L/hr	62	425
Solution Strength	%	20	
Type of Storage Tank		FRP	
Number of Tanks		1	2
Volume, each Tank, for 1 hr detention time	m^3	0.4	1.9
Type of Metering		Eductor	
Number of Eductors		2 (1 standby)	

Capacity, each Eductor	L/hr	337	2,310
Ferric Sulfate			
Application Point		Rapid Mix Basins, First Stage	
Design Capacity	kg/day	625	4,280
Delivered Chemical		Granular, 68 or 76% $Fe_2(SO_4)_3$, Bags	
Bulk Density	kg/m^3	1,025	
Type of Feeder		Volumetric	
Number of Feeders		2 (1 standby)	
Capacity, each Feeder	L/hr	28.3	170
Solution Strength	%	10	
Type of Storage Tank		Type 316 Stainless Steel	
Number of Tanks		2	
Volume, each Tank, for 1 hr detention time	m^3	0.4	1.9
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	3 (1 standby)
Capacity, each Pump	L/hr	260	890
Sodium Hypochlorite			
Application Point		Backpulse Line	
Design Capacity Maintenance Clean Recovery Clean	 kg/day kg/day	 269 10,750	 614 24,570
Delivered Chemical		Liquid, 12%, Bulk	
Type of Storage Tank		Vertical, cylindrical, closed top, FRP	
Number of Tanks		2	
Volume, each Tank, for 30 day storage time	m^3	7.6(1)	7.6(1)
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps Maintenance Clean Recovery Clean		 2 (1 standby) 2 (1 standby)	
Capacity, each Pump Maintenance Clean Recovery Clean	 L/hr L/hr	 93.5 3,740	 213.5 8,540
Citric Acid			
Application Point		Backpulse Line	
Design Capacity	kg/day	48.47	103.95
Delivered Chemical		Powder, 99%, Bags	
Bulk Density	kg/m^3	1,665	
Type of Feeder		Volumetric	
Number of Feeders		1	
Capacity, each Feeder	L/hr	29	62
Solution Strength	%	50	
Type of Storage Tank		FRP	
Number of Tanks		1	
Volume, each tank, for 1 hour	m^3	0.4	1.9

detention time			
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	3,600	7,700
Sodium Bisulfite			
Application Point		Recirculation Line	
Design Capacity	kg/day	1,163	2,495
Delivered Chemical		Granular, 100%, Bags	
Bulk Density	kg/m^3	1,280	
Type of Feeder		Volumetric	
Number of Feeders		1	
Capacity, each Feeder	L/hr	37.9	81.2
Solution Strength	%	5	
Type of Storage Tank		FRP	
Number of Tanks		1	
Volume, each Tank, for 1 day detention time	m^3	0.4	0.4
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	2 (1 standby)
Capacity, each Pump	L/hr	1,000	2,150
Sodium Hydroxide			
Application Point		Recirculation Line	
Design Capacity	kg/day	2,047	4,391
Delivered Chemical		Liquid, 25%, Bulk	
Type of Storage Tank		Vertical, cylindrical, closed top, FRP	
Number of Tanks		1	2
Volume, each Tank, for 30 day storage time	m^3	7.6(1)	7.6(1)
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	2 (1 standby)
Capacity, each Pump	L/hr	325	700
Chlorine (used to generate chlorine dioxide)			
Application Point		Chlorine Dioxide Generators	
Design Capacity	kg/day	31.3	213.8
Delivered Chemical		Liquid, Ton Containers	
Type of Chlorinator		Gas	
Number of Chlorinators		2 (1 standby)	
Capacity, each Chlorinator	kg/day	227	227
Chlorine (used for final disinfection)			
Application Point		Finished Water Storage Tank Influent	
Design Capacity	kg/day	31.3	213.8
Delivered Chemical		Liquid, Ton Containers	
Type of Chlorinator		Gas	
Number of Chlorinators		2 (1 standby)	
Capacity, each Chlorinator	kg/day	227	227

(4) Minimum volume to allow for truck delivery.

Table G-16 lists the chemical requirements for periodic cleaning of the membranes.

Table G-16
Chemical Requirements for Ultrafiltration Membrane Cleaning

Item	Units	KAC WTP	Wehdeh WTP
Maintenance Clean			
Frequency of Cleaning		Once per Day	
Membrane Tank Cleans per day		4	10
Sodium Hypochlorite	kg/clean	2.42	5.20
Sodium Bisulfite ($NaHSO_3$)	kg/clean	0.13	0.30
Sodium Hydroxide (NaOH)	kg/clean	0.05	0.12
Recovery Clean			
Frequency of Cleaning		Once per Month	
Membrane Tank Cleans per month		4	10
Sodium Hypochlorite	kg/clean	12.12	25.99
Citric Acid	kg/clean	48.47	103.95
Sodium Bisulfite ($NaHSO_3$)	kg/clean	12.39	26.62
Sodium Hydroxide	kg/clean	25.99	55.75
Annual Chemical Use			
Sodium Hypochlorite	kg	4,115	22,099
Citric Acid	kg	2,327	12,474
Sodium Bisulfite ($NaHSO_3$)	kg	785	4,289
Sodium Hydroxide	kg	1,321	7,128

Table G-17 lists the estimated capital costs for ultra-filtration treatment at the two WTPs.

Table G-17: Estimated Costs, Ultra-Filtration Treatment Processes

Item	Units	KAC WTP	Wehdeh WTP
MOBILIZATION AND DEMOBILIZATION		**$ 150,000**	**$ 450,000**
SITE WORKS		**$ 388,000**	**$ 1,615,000**
Land Cost	LS	$ 30,000	$ 200,000
Site Grading	LS	$ 5,000	$ 50,000
Site Structural Works	LS	$ 25,000	$ 100,000
Roads, parking and paved areas	LS	$ 54,000	$ 180,000
Landscaping (Tree plantings)	LS	$ 24,000	$ 80,000
Yard piping	LS	$ 200,000	$ 800,000
Yard Electrical Power and Lighting	LS	$ 15,000	$ 75,000
Yard Instrumentation/Control Cables and Equipment	LS	$ 10,000	$ 30,000
Fencing and Gates	LS	$ 25,000	$ 100,000
BUILDINGS		**$ 290,000**	**$ 777,500**
Admin building including control room and lab	LS	$ 100,000	$ 200,000
Chemical building (CIO2, MnO4, PAC)	LS	$ 125,000	$ 400,000
Chlorine building	LS	$ 40,000	$ 115,000
Blower room	LS	$ 25,000	$ 62,500
PROCESS UNITS, Civil Works		**$ 486,062**	**$ 2,140,858**
Inlet Structure	LS	$ 15,000	$ 50,000
Adsorption	LS	$ 69,175	$ 259,515
Coagulation basin	LS	$ 12,851	$ 32,942
Flocculation Tank	LS	$ 39,022	$ 146,524
Ultra-Filtration Tank	LS	$ 94,034	$ 416,480
Finshed Water Tanks	LS	$ 187,749	$ 808,950
Sludge Drying Beds	LS	$ 68,232	$ 426,447
PROCESS UNITS, Equipment		**$ 4,898,750**	**$ 18,237,000**
Rapid Mixers/Flocculators	LS	$ 155,250	$ 316,250
Ultra-filtration Membrane Treatment System	LS	$ 3,657,000	$ 15,295,000
Metering Pumps	LS	$ 28,750	$ 46,000
Chlorinators	LS	$ 11,500	$ 28,750
Chemical Storage Tanks	LS	$ 17,250	$ 23,000
Dry Feed Systems	LS	$ 230,000	$ 425,500
Chlorine Dioxide Generators	LS	$ 11,500	$ 28,750
Instrumentation Work	LS	$ 157,500	$ 420,000
Electrical Work	LS	$ 630,000	$ 1,653,750
Subtotal		**$ 6,212,812**	**$ 23,220,358**
Contractors OH&Profit 35%		**$ 2,174,484**	**$ 8,127,125**
Contingencies 20%		**$ 1,677,459**	**$ 6,269,497**
Total Estimated Cost		**$ 10,064,756**	**$ 37,616,980**

In addition to the above capital costs, every ten years the membranes will have to be replaced at costs that are currently US$498,300 and US$2,906,800 for the KAC and Wehdeh WTPs, respectively.

G.3.2.2 Micro-filtration Membranes

CMF-S hollow fiber membranes have a nominal pore size of 0.1 microns. The small pore size, while larger than the pore size in ultrafiltration membranes, also excludes particulate matter including *Giardia* cysts and *Cryptosporidium* oocysts from the treated water. Additionally, some viruses are removed by a combination of adsorption onto the solids in the process tank and by direct size exclusion. CMF-S membranes can achieve ≥ 4 log removal of *Giardia* cysts and *Cryptosporidium* oocysts and ≥ 2.0 log removal of viruses.

The membranes operate under a vacuum created within the hollow membrane fibers by a filtrate pump. Treated water is drawn through membrane pores and enters the inside of the hollow fibers. Water then flows through the filtrate pump to the finished water storage tank or directly to the distribution system.

CMF-S membranes are manufactured in discrete units called "modules." A group of four modules forms a "clover" which is then connected to a support "rack." Each rack assembly can accommodate up to 9 clovers or 36 modules. The rack assemblies are manifolded together and lowered into a concrete or Type 316 stainless steel tank called a "cell" that is filled with the source water. Each cell can accommodate up to 20 racks. The design of the filtrate header allows cells to be isolated for the purpose of performing membrane integrity hold tests.

In addition to particulate (turbidity) removal and pathogen removal, the membranes are highly effective in removing color, total organic carbon (TOC), and dissolved organic carbon (DOC) when combined with coagulant addition. The coagulant adsorbs dissolved organics that would otherwise pass through the membranes, but are removed once adsorbed onto a particle. Coagulant is injected into the raw feed water to allow the formation of pin-sized floc particles that only need to be larger than the membrane pores for removal by the membranes. In this case, pretreatment will require the addition of chlorine dioxide for oxidation, PAC for adsorption, and ferric sulfate for coagulation with a minimum flocculation time of 8 to 10 minutes.

Flow through the membranes is monitored, as is the vacuum pressure applied. As water is drawn through the membranes during filtration, solids are removed at the membrane surface and accumulate in a manner similar to a conventional granular media filter. The effect of solids accumulation on the membrane surface is to restrict flow through the membranes, eventually reaching a point where cleaning is required to maintain the design operating flux (i.e., permeability). Cleaning is achieved periodically by three separate and distinct steps:

- Reversing the flow through the membranes (termed "backwashing") using filtrate previously filtered by the membrane system and stored for this purpose. The design backwash frequency is every 30 minutes for 3 minutes. Backwashing consists of several steps:

  1. A cell is isolated for backwashing by stopping the feed water to the cell.

2. The water level in the cell is lowered to a set backwash level by allowing the filtrate pump to continue pumping. Once the backwash level is reached, the pump is stopped. This lowers the amount of waste backwash volume.

3. Low pressure air scour scrubs the outer surface of the fibers and loosens solids from the module. Simultaneously, filtrate is introduced in reverse flow to backwash the fibers. This step takes approximately 15 seconds to complete.

4. Aeration continues after the end of the reverse filtration for approximately 30 seconds. Before the end of this step, the cell is partially drained.

5. The cell is completely drained and the cell is refilled with feed water and the filtrate pump is restarted.

- A chemical maintenance wash (CMW) will be accomplished once a day to restore part of the permeability and to lengthen the interval between CIP cleanings. The cell enters into a backwash sequence during which the modules are soaked in a solution of chorine.

  The CMW uses the same auxiliary equipment required for CIP cleanings. After a normal backwash, the cell is filled with raw water. The water is recirculated using the filtrate pump and sodium hypochlorite is injected in-line to achieve the desired concentration. Recirculation is followed by a soak, cell drain down, backwash (without air), rinse and filter to waste. The cell is then filled with feed water and returned to filtration. The CMW sequence takes approximately 30 minutes for completion. Sodium bisulfite can be added to the solution being discharged to eliminate any chorine residual to meet the requirements for discharge.

- Once a month the membranes will require cleaning to restore the flux rate, as backwashing alone is not adequate for this purpose. This step is termed "clean-in-place" or CIP. The CIP sequence is generally a minimum of two hours in duration. Each CIP includes two cleaning regimes carried out sequentially. The first cleaning is performed using a citric acid or sulfuric acid solution at 35 C. The second regime utilizes an unheated solution of sodium hypochlorite. The principle steps are as follows:

1. The cell is isolated for cleaning by stopping the feed water to the cell.

2. The cell is backwashed to remove excess solids and maximize chemical efficiency. The cell is drained to waste. At the end of this step, low pressure air is introduced inside the filtrate manifold to drain the filtrate side of the modules and the filtrate headers. This step ensures that no dilution or reduction in temperature occur when the CIP solution is transferred into the cell.

3. The cell is filled with the acid or chlorine solution up to the backwash level. When citric acid is used, the solution is reused up to 4 times. The acid solution is brought up to the appropriate temperature by an immersion heater in the chemical storage tank and then transferred to the cell.

4. The solution in the cell is then recirculated by the filtrate pump. During recirculation, an in-line heater maintains the temperature of the cleaning solution.

5. The modules are left to soak for a preset time.

6. The soak and recirculation steps are alternated automatically.

7. The cleaning solution is drained away from the cell and discharged to a neutralization tank or, if applicable, to the acid storage tank for reuse. Sodium hydroxide and sodium bisulfite can then be added to the solution in the neutralization tank to adjust the pH of the solution and to eliminate any chorine residual to meet the requirements for discharge. The solution is then discharged by gravity to a sewer or, if a sewer is not available, pumped to a truck for transport to a wastewater treatment plant.

8. The cell is refilled with feed water and backwashed to remove residual chemical. All rinse water is then disposed of with the backwash waste.

After approximately ten years, the life of the membranes will have been reached and it will be necessary to replace them. This is an expensive undertaking and needs to be factored into the cost of a membrane plant.

On the average, three to four percent of the influent flow to the membrane process will be lost due to the backwash and recovery cleaning steps. In other words, the "recovery rate" will be 96 to 97 percent. Therefore, the raw water pumps and pretreatment facilities, as well as the membrane facilities themselves, need to be oversized in order to achieve the design flows at the effluent end of the two treatment plants.

The filtrate water storage tank is filled automatically with filtrate during normal plant operation. When the level in the tank is low, filtrate is automatically diverted into the tank which is equipped with a level transmitter.

Clarity of the treated water from each train is monitored continuously by online turbidimeters and particle counters. A membrane is a physical barrier and solids levels in the treated water are normally very low. An increase in turbidity or particle counts can indicate either a membrane failure or possibly a leaking or damaged pipe. To protect the integrity of the treated water and also to maintain the long-term operating performance of the membrane system, in the event of high turbidity or particle count the affected process stream will be automatically shut down. The source of particulate entry into the filtrate can then be determined by bubble point tests to locate the place where the membrane has been compromised.

Disinfection

A significant amount of pre-disinfection will be provided through the addition of chlorine dioxide and potassium permanganate to the raw water. However, it will be necessary to apply a final disinfectant to the water after filtration to ensure that all remaining pathogens are inactivated and to provide a disinfecting residual throughout the distribution system. Because it is less expensive and because chlorine dioxide can cause taste and odor problems brought about by reformed ClO_2 in the distribution system, chlorine is recommended to provide final disinfection.

Chlorine should be applied to a finished water storage tank or clearwell, baffled to prevent short-circuiting. To inactivate/remove viruses and *Giardia*, the Jordanian Standard for Grade 3 raw waters has specified 4 log (99.99%) inactivation/removal for *Giardia* and 5 log (99.999%) for viruses. A 4 log (99.99%) removal credit for *Giardia* and 2 log (99.0%) removal credit for viruses can be taken for an efficient membrane water treatment plant. The remaining virus log requirements (3 logs) must be implemented by disinfectant inactivation. However, a minimum of 0.5 log inactivation for *Giardia* should be provided at all times.

The applicable USEPA Giardia and virus inactivation tables for chlorine have been applied to the two new WTPs; i.e., pH <= 9.0, the worse case water temperature of 10^{o} C and a chlorine concentration of 1.0 mg/L. From these tables, *Giardia* inactivation requires a CT (concentration x time) of 39 mg/L-min. With a chlorine residual of 1.0 mg/L, a contact time (T_{10}) of 39 minutes needs to be provided at the design flow. Assuming an average baffling system, the short-circuiting factor (T_{10}/t) will be about 0.5. Therefore, the hydraulic residence time that needs to be provided in the storage tank is 78 minutes.

We recommend that two tanks or a tank with two compartments be used, and that each tank or compartment have the volume to meet the required hydraulic residence time. This will allow one tank or compartment to be removed from service for maintenance and still maintain the required CT of 39 mg/L-min.

Tables G-18 and **G-19** list the design criteria for the main process units and the chemical handling systems, respectively.

Table G-18
Design Criteria for Microfiltration Membrane Treatment

Item	Units	KAC WTP	Wehdeh WTP
Plant Capacity (effluent)	m^3/hr	600	4,110
Design Recovery Rate	%	95.3	96.9
Required Influent Flow	m^3/hr	630	4,240
Oxidation		In Raw Water Pipeline	
Adsorption			
Number of Contact tanks		1	
Detention Time	Min	30	
Volume of Contact Tank	m^3	315	2,120
Size of Tank	M	4 x 17.5 x 4.5 swd	10 x 47.1 x 4.5 swd
Coagulation			
Configuration		1 train w/ 2 basins in series	2 trains w/ 2 basins in series
Number of Vertical Turbine Mixers		2	4
Detention Time, each Basin	Sec	60	30
Volume, each Basin	m^3	10.5	17.7
Size, each Basin	M	1.55 x 1.55 x 4.5 swd	2.0 x 2..0 x 4.5 swd
Energy Gradient, *G*, first stage	sec^{-1}	600	
Energy Gradient, *G*, second stage	sec^{-1}	300	
Flocculation			
Configuration		2 trains w/ 2 compartments in series	4 trains w/ 2 compartments in series
Detention Time, each Compartment	Min	5	5

Volume, each Compartment	m^3	26.3	88.3
Size, each Compartment	M	2.40 x 2.40 x 4.5 swd	4.45 x 4.45 x 4.5 swd
Energy Gradient, *G*, first stage	sec^{-1}	80	
Energy Gradient, *G*, second stage	sec^{-1}	50	
Membrane Filtration			
Number of Cells		3	6
Number of Racks, each Cell		6	16
Total Number of Racks		18	96
Number of Modules, each Rack		36	
Total Number of Modules		648	3,456
Surface Area, each Module	m^2	7.7	
Design Flux (nominal) All Cells One Train Off-line	 $m^3/m^2/day$ $m^3/m^2/day$	 0.89 1.34	 1.26 1.52
Volume (displaced), each Cell	m^3	23.2	58.6
Size, each Cell	M	2.20 x 3.75 x 4.2 swd	5.55 x 3.75 x 4.2 swd
Number of Aeration Blowers		2 (1 standby)	
Capacity, each Blower	m^3/min	43.4	115.8
Number of Filtrate Pumps		3	6
Capacity, each Pump	m^3/hr	210	707
Number of Backwash Tanks		1	
Number of Backwash Pumps		2 (1 standby)	
Disinfection			
Configuration of Finished Water Storage Tank		1 tank w/ 2 compartments	1 tank w/ 2 compartments
Hydraulic Detention Time, each Compartment	Min	78	78
Volume, each Compartment	m^3	820	5,510
Size, each Compartment	M	13.5 x 13.5 x 4.5 swd	35 x 35 x 4.5 swd
Chemicals (both WTPs)			
		Average	**Maximum**
Chlorine Dioxide	mg/L	1.5	3
Potassium Permanganate	mg/L	3	3
Powdered Activated Carbon	mg/L	15	30
Ferric Sulfate	mg/L	15 summer; 25 winter	40

Sodium Hypochlorite			
Maintenance Wash	mg/L	50(1)	50(1)
CIP Clean	mg/L	250(1)	2,000(1)
Citric Acid	mg/L	1,000(1)	8,000(1)
Sodium Bisulfite			
Maintenance Wash	mg/L	n/a	50(1)
CIP Clean	mg/L	n/a	250(1)
Sodium Hydroxide	mg/L	n/a	440(1)
Chlorine			
Chlorine Dioxide	mg/L	1	2
Final Disinfection	mg/L	1	2
swd = side water depth n/a = not applicable (1) assumed same as for UF membranes			

Table G-19
Design Criteria for Chemical Handling Systems for Microfiltration Membrane Treatment

Item	Units	KAC WTP	Wehdeh WTP
Chlorine Dioxide (generated on site by combining sodium chlorite and chlorine)			
Application Point		Raw Water Transmission Main	
Design Capacity	kg/day	45.3	305.1
Delivered Chemical		Liquid	
Number of Generators		2 (1 standby)	
Capacity, each Generator	kg/hr	2.5	18.9
Sodium Chlorite (used to generate chlorine dioxide)			
Application Point		Chlorine Dioxide Generator	
Design Capacity	kg/day	60.8	408.8
Delivered Chemical		Liquid, 25%, Bulk	
Type of Storage Tanks		Vertical, cylindrical, closed top, FRP	
Number of Tanks		2	
Volume, each Tank, for 30 day storage time	m^3	7.6(1)	11.4
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	8.6	58.0
Potassium Permanganate			
Application Point		Raw Water Transmission Main	
Design Capacity	kg/day	45.3	305.1
Delivered Chemical		Crystals, 97%, Drums	
Bulk Density	kg/m^3	1,450	
Type of Feeder		Volumetric	
Number of Feeders		1	2 (1 standby)
Capacity, each Feeder	L/hr	1.7	8.5
Solution Strength	%	1	
Type of Storage Tank		Vertical, cylindrical, open top, FRP	

Number of Tanks		1	2 (1 standby)
Volume, each Tank, for 24 hr detention time	m^3	0.28	1.32
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	192	1,272
Powdered Activated Carbon			
Application Point		Carbon Contact Tank	
Design Capacity	kg/day	453	3,051
Delivered Chemical		Powder, 100%, Bags	
Bulk Density	kg/m^3	340	
Type of Feeder		Volumetric	
Number of Feeders		1	2 (1 standby)
Capacity, each Feeder	L/hr	62	425
Solution Strength		20	
Type of Storage Tank		FRP	
Number of Tanks		1	2
Volume, each Tank, for 1 hr detention time		0.4	1.9
Type of Metering		Eductor	
Number of Eductors		2 (1 standby)	
Capacity, each Eductor	L/hr	327	2,198
Ferric Sulfate			
Application Point		Rapid Mix Basins, First Stage	
Design Capacity	kg/day	604	4,068
Delivered Chemical		Granular, 68 or 76% $Fe_2(SO_4)_3$, Bags	
Bulk Density	kg/m^3	1,025	
Type of Feeder		Volumetric	
Number of Feeders		2 (1 standby)	
Capacity, each Feeder	L/hr	28.3	170
Solution Strength	%	10	
Type of Storage Tank		Type 316 Stainless Steel	
Number of Tanks		2	
Volume, each Tank, for 1 hr detention time	m^3	0.4	1.9
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	3 (1 standby)
Capacity, each Pump	L/hr	251	846
Sodium Hypochlorite			
Application Point		Recirculation Line	
Design Capacity Maintenance Wash CIP Clean	 kg/day kg/day	 252 10,080	 848 33,920
Delivered Chemical		Liquid, 12%, Bulk	
Type of Storage Tank		Vertical, cylindrical, closed top, FRP	
Number of Tanks		2	

Volume, each Tank, for 30 day storage time	m^3	7.6(1)	7.6(1)
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps Maintenance Wash CIP Clean		 2 (1 standby) 2 (1 standby)	
Capacity, each Pump Maintenance Wash CIP Clean	 L/hr L/hr	 87.6 3,760	 294.9 11,790
Citric Acid			
Application Point		Recirculation Line	
Design Capacity	kg/day	48.47(2)	103.95(2)
Delivered Chemical		Powder, 99%, Bags	
Bulk Density	kg/m^3	1,665	
Type of Feeder		Volumetric	
Number of Feeders		1	
Capacity, each Feeder	L/hr	29(2)	62(2)
Solution Strength	%	50	
Type of Storage Tank		FRP	
Number of Tanks		1	
Volume, each tank, for 1 hour detention time		0.4	1.9
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	
Capacity, each Pump	L/hr	3,600(2)	7,700(2)
Sodium Bisulfite			
Application Point		Recirculation Line	
Design Capacity	kg/day	1,163(2)	2,495(2)
Delivered Chemical		Granular, 100%, Bags	
Bulk Density	kg/m^3	1,280	
Type of Feeder		Volumetric	
Number of Feeders		1	
Capacity, each Feeder	L/hr	37.9(2)	81.2(2)
Solution Strength	%	5	
Type of Storage Tank		FRP	
Number of Tanks		1	
Volume, each Tank, for 1 day detention time	m^3	0.4	0.4
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	2 (1 standby)
Capacity, each Pump	L/hr	1,000(2)	2,150(2)
Sodium Hydroxide			
Application Point		Recirculation Line	
Design Capacity	kg/day	2,047(2)	4,391(2)
Delivered Chemical		Liquid, 25%, Bulk	

Type of Storage Tank		Vertical, cylindrical, closed top, FRP	
Number of Tanks		1	2
Volume, each Tank, for 30 day storage time	m^3	7.6(1)	7.6(1)
Type of Metering Pump		Simplex, diaphragm liquid end, variable speed (SCR)	
Number of Metering Pumps		2 (1 standby)	2 (1 standby)
Capacity, each Pump	L/hr	325(2)	700(2)
Chlorine (used to generate chlorine dioxide)			
Application Point		Chlorine Dioxide Generators	
Design Capacity	kg/day	30.2	203.4
Delivered Chemical		Liquid, Ton Containers	
Type of Chlorinator		Gas	
Number of Chlorinators		2 (1 standby)	
Capacity, each Chlorinator	kg/day	227	227
Chlorine (used for final disinfection)			
Application Point		Finished Water Storage Tank Influent	
Design Capacity	kg/day	30.2	203.4
Delivered Chemical		Liquid, Ton Containers	
Type of Chlorinator		Gas	
Number of Chlorinators		2 (1 standby)	
Capacity, each Chlorinator	kg/day	227	227
(1) Minimum volume to allow for truck delivery. (2) Assumed same as for UF membranes			

Table G-20 lists the chemical requirements for periodic cleaning of the membranes.

Table G-20
Chemical Requirements for Micro-filtration Membrane Cleaning

Item	Units	KAC WTP	Wehdeh WTP
Chemical Maintenance Wash			
Frequency of Washing		Once per Day	
Membrane Cell Washes per day		3	6
Sodium Hypochlorite	kg/wash	0.36	1.00
Sodium Bisulfite ($NaHSO_3$)	kg/wash	0.54	1.45
CIP Clean			
Frequency of Cleaning		Once per Month	
Membrane Cell Cleans per month		3	6
Sodium Hypochlorite	kg/clean	1.45	3.95
Citric Acid	kg/clean	36.02	98.25
Sodium Bisulfite ($NaHSO_3$)	kg/clean	2.13	5.81
Sodium Hydroxide	kg/clean	29.53	80.56
Annual Chemical Use			
Sodium Hypochlorite	kg	446	2,474
Citric Acid	kg	1,297	7,074
Sodium Bisulfite ($NaHSO_3$)	kg	668	3,594
Sodium Hydroxide	kg	1,063	5,800

Table G-21 lists the estimated capital costs for micro-filtration treatment at the two WTPs.

In addition to the above capital costs, every ten years the membranes will have to be replaced at costs that are currently US$291,600 and US$1,555,200 for the KAC and Wehdeh WTPs, respectively.

Table G-21: Estimated Costs, Micro-Filtration Treatment Processes

Item	Units	KAC WTP	Wehdeh WTP
MOBILIZATION AND DEMOBILIZATION		**$ 150,000**	**$ 450,000**
SITE WORKS		**$ 388,000**	**$ 1,615,000**
Land Cost	LS	$ 30,000	$ 200,000
Site Grading	LS	$ 5,000	$ 50,000
Site Structural Works	LS	$ 25,000	$ 100,000
Roads, parking and paved areas	LS	$ 54,000	$ 180,000
Landscaping (Tree plantings)	LS	$ 24,000	$ 80,000
Yard piping	LS	$ 200,000	$ 800,000
Yard Electrical Power and Lighting	LS	$ 15,000	$ 75,000
Yard Instrumentation/Control Cables and Equipment	LS	$ 10,000	$ 30,000
Fencing and Gates	LS	$ 25,000	$ 100,000
BUILDINGS		**$ 290,000**	**$ 777,500**
Admin building including control room and lab	LS	$ 100,000	$ 200,000
Chemical building (CIO2, MnO4, PAC)	LS	$ 125,000	$ 400,000
Chlorine building	LS	$ 40,000	$ 115,000
Blower room	LS	$ 25,000	$ 62,500
PROCESS UNITS, Civil Works		**$ 444,174**	**$ 1,889,066**
Inlet Structure	LS	$ 15,000	$ 50,000
Adsorption	LS	$ 66,813	$ 249,195
Coagulation basin	LS	$ 12,851	$ 32,200
Flocculation Tank	LS	$ 38,248	$ 146,524
Micro-Filtration Tank	LS	$ 58,619	$ 209,950
Finshed Water Tanks	LS	$ 184,413	$ 774,750
Sludge Drying Beds	LS	$ 68,232	$ 426,447
PROCESS UNITS, Equipment		**$ 3,541,750**	**$ 9,267,000**
Rapid Mixers/Flocculators	LS	$ 155,250	$ 316,250
Micro-filtration Membrane Treatment System	LS	$ 2,300,000	$ 6,325,000
Metering Pumps	LS	$ 28,750	$ 46,000
Chlorinators	LS	$ 11,500	$ 28,750
Chemical Storage Tanks	LS	$ 17,250	$ 23,000
Dry Feed Systems	LS	$ 230,000	$ 425,500
Chlorine Dioxide Generators	LS	$ 11,500	$ 28,750
Instrumentation Work	LS	$ 157,500	$ 420,000
Electrical Work	LS	$ 630,000	$ 1,653,750
Subtotal		**$ 4,813,924**	**$ 13,998,566**
Contractors OH&Profit 35%		**$ 1,684,874**	**$ 4,899,498**
Contingencies 20%		**$ 1,299,760**	**$ 3,779,613**
Total Estimated Cost		**$ 7,798,557**	**$ 22,677,677**

G.4 Summary and Conclusions

The estimated costs for the three treatment alternatives are compared in **Table G-22**. A conventional filtration treatment system would be the least expensive alternative, followed in turn by the micro-filtration and ultra-filtration alternatives. It can be seen that ultra-filtration is the most expensive alternative by a considerable margin; while ultra-filtration provides removal of smaller particles than micro-filtration, the additional cost is not considered to be warranted, since it would not provide any noticeable public-health benefit in terms of removal of nematodes, viruses, or parasites. Given that much of the Yarmouk River basin lies in Syria, beyond the control of Jordanian public health authorities, micro-filtration is considered preferable to conventional filtration because of the improved removal efficiency at only a nominal increase in capital costs. Similarly, in terms of annual costs of chemicals, energy, operations and maintenance, the micro-filtration alternative would cost somewhat more than conventional filtration, but the increase in cost is considered affordable and well-spent in terms of protecting public health. However, it is considered desirable that a final decision on the preferred treatment process be deferred to the final design phase, when additional factors that influence the decision may come to light.

Table G-22: Summary of Estimated Costs of Treatment Alternatives

Treatment Process Alternative	KAC WTP	Al Wehdeh WTP
Conventional Filtration	$6,700,000	$22,295,000
Micro-Filtration	$7,799,000	$22,678,000
Ultra-Filtration	$10,065,000	$37,617,000

Annex G.1

Recommendation

Microbiological Standards Of The Quality Of Surface Water Sources And Groundwater Sources That Are Subject to Contamination Risk From Surface, And Minimum Treatment Requirements To Utilize Those Sources.

Prepared by:

The Higher Committee for Water Quality

July 2001

(Signatures of Committee Members)

1- Scope:

This standard is for the minimum treatment requirements of public and private surface water and groundwater sources under the direct influence of surface contamination intended for drinking and household use. These standards will not apply to protected groundwater sources.

2- Definitions:

2-1 Surface Water:

Is the running water or water of lakes, dams and pools.

2-2 Groundwater under the influence of surface contamination: Groundwater of wells or springs whose physical and chemical specifications change in accordance to the quality of surface water that affect it, and whose microbiological aspects point to the possibility of disease links by containing:

- Escherichia Coli (*E*. Coli) in numbers exceeding 20 /100ml.

2-3 Disinfection:

The operation of removal of disease causing microorganisms , and indicator microorganisms by using disinfectants such as chlorine, chloride-dioxide, ultra-violet irradiation or ozone or disinfectants recognized by official specialists.

2-4 Filtration:

Passage of water through filters to remove disease-causing microorganisms and suspended matter.

2-5 Protected water sources:

Those are the wells and springs for which one year of samples confirm stability of microbial, physical and chemical quality. And whose *E*.coli count do not exceed 20/100ml in any sample, taken at least once every four months

3- Classification of Water Sources:

The water sources that fall under these standards and requirements are classified in three groups:

3-1 Group 1:

The water sources that could be used for drinking after disinfection only.

a. Criteria:
    1. The *E*.Coli count does not exceed 20 /100ml in more that 20% of one-year samples.
    2. The turbidity concentration in any single sample does not exceed 5 NTU.
    3. The pH value is between 6.5 and 8.5.

b. Operational Procedures:

The source will be shut down in any of the following conditions:

1. When the criteria of items 2 or 3 are exceeded. The source will not be used again unless all criteria mentioned hereinabove is met for two consecutive days of sampling
2. If the E.coli count exceeds 50 /100ml in any single sample. The source will be operational after the *E*.coli counts is less that 50 /100ml in all samples taken in three consecutive days with an average of at least two tests/day, with two-hour periods between samples.
3. If the number of samples with more than 20 *E.* coli /100ml exceed 20% of samples tested during one year (samples tested during shutdowns are excluded). The source will be operational after setting up a treatment plant that has the necessary treatment capabilities in accordance with the requirements for Group 2 and Group 3 water sources.

3-2 Group 2:

Those water sources that could be used for drinking after filtration and disinfection:

a. Criteria:

The sources which E.coli count exceed 20 /100ml in more that 20% of the samples, and does not exceed 2000 /100ml in more that 20% of samples of one year.

b. Required Treatment:

These sources will be treated using any of the following methods before the post disinfection, with the condition that the treatment guarantees 4-log (99.99%) removal of viruses and 3-log (99.9%) removal of Giardia and Cryptosporidium.

1. Rapide filtration
2. Membrane filtration, Microfiltration, Ultrafiltration & Nanoflitration
3. Reverse Osmosis (RO)
4. Slow Sand filtration after coagulation, mixing and sedimentation.
5. Filtration using any method approved by the authorized parties.

c. Operational Procedures:

The water source will be shut down in any of the conditions:

1. If the *E*.coli count exceeds 5000 /100ml in any single sample. The plant will not be operated unless the E. Coli counts in all samples taken in three consecutive days is less than 5000 /100ml , with an average of at least two samples a day with two hours period between samples

2. If the number of samples with more than 2000 *E.* Coli /100ml exceed 20% of samples tested during one year (samples tested during shutdowns are excluded). The source will be operational after setting up a treatment plant that has the necessary treatment

capabilities in accordance with the requirements for Group 3 water sources.

3-3 Group 3:

Sources that could be used for drinking only with intensive treatment:

a. Criteria:

These are the sources which E.Coli count exceeds 2000 /100ml in more than 20% of one year samples

b. Required Treatment:

Over and above the requirements for Group 2, these sources will be subjected to additional treatment to guarantee that treatment will collectively achieve 5-log (99.999%) removal of viruses and 4-log removal (99.99%) of Giardia and Cryptosporidium

c. Operational Procedures:

The source will be shut down if the E.coli count exceeds 20000 /100ml in any sample. The source will not resume its operations unless the E. Coli count of all samples taken in three consecutive days are less than 20000 /100ml conducting at least two sample tests/day with a two hour period between samples.

4- General Rules:

1. In case the technical capability for E. Coli count testing is not available, the "Total Thermotolerant Coliform Count" (TTCC) will be adopted with the same criteria.

2. The water sources classified under these standards will be subject to Quality Control with an average of at least two samples/week for raw water.

3. The owner of the water source will provide to the authorities in charge of controlling the water quality all necessary scientific documents to prove the efficiency of proposed or used treatment units.